Maine Geological Survey
Studies in Maine Geology: Volume 5
1989

The Lithologic and Structural Controls on the Geomorphology of the Mountainous Areas in North-Central Maine

Lindley S. Hanson
Department of Geological Sciences
Salem State College
Salem, Massachusetts 01970

Dabney W. Caldwell
Department of Geology
Boston University
Boston, Massachusetts 02215

ABSTRACT

In the mountainous areas of north-central Maine, the highest peaks are commonly formed in hornfelsic rocks which surround Acadian plutons. Quartzites and felsic volcanic rocks form ridges and steep-sided mountains. The only summit supported by granitic rock is Mount Katahdin, which has a resistant cap of granophyre that overlies the weaker granular-textured granite. Lowlands are underlain by plutonic rock, of both granitic and gabbroic composition, and by pervasively cleaved pelitic rocks.

In Maine, the area of greatest relief occurs in a northeast-trending belt, referred to here as the Central Highlands. High peaks that exceed 4000 feet (1220 m) are most abundant in the Rangeley area, western Maine. The highlands continue into New Hampshire to the even higher peaks of the Presidential Range. In the center of the belt, near Greenville, there are no peaks that rise above 4000 feet (1220 m). All other high elevations are associated with the Katahdin massif, near the northeastern terminus of this mountainous region. The rugged topography of the Central Highlands has formed from the erosion of the Acadian orogen, which was either originally higher toward the southwest or has been differentially uplifted by one or more subsequent thermal events.

Trellis drainage systems are best developed in areas of low-grade, regionally metamorphosed sandstones and pelites. Major streams are largely parallel or perpendicular to the fold axes. Radial drainage patterns are found on many of the higher summits, such as Katahdin, Big Squaw, Sugarloaf, and Jo-Mary Mountains.

Lake basins formed in areas of plutonic rock dominate the headwaters of the major rivers that drain the mountainous region of north-central Maine. However, lakes are conspicuously absent in the drainage system once the rivers leave the highlands. Lake basins are locally common in the highly cleaved pelites that underlie the Northern Lowlands north of the Central Highlands.

INTRODUCTION

It has long been recognized that in regions where erosion has become the principal agent of landscape evolution, topographic expression is governed by the relative resistance of the underlying bedrock (Davis, 1909). Resistance is largely determined by rock composition, texture, and planes of weakness that are either inherent (e.g. bedding planes) or the result of deformation (e.g. jointing or cleavage). In the Appalachian Highlands from Alabama to Vermont, Hack (1979) has demonstrated that topography is controlled by lithology, and that recent differential uplift cannot account for the relief observed. In New Hampshire, Thompson (1985) has shown that the relief of Mt. Monadnock is related to lithology; a refolded quartzite package supports the summit while plutonic and less resistant metasedimentary rocks underlie the adjacent lowlands.

The mountainous area of north-central Maine is underlain by Precambrian to Middle Devonian metasedimentary and plutonic rocks. The most influential control on relief in this area is clearly the variability of the lithologies exposed. A generalized list of lithologies occurring in north-central Maine is presented in Table 1. The various rock types are arranged, from top to bottom, in order of decreasing resistance to erosion.

Other factors being equal, a terrain composed entirely of rocks having the same resistance will not exhibit as high relief as one underlain by a variety of rock types. For example, the Katahdin region has a maximum relief of 4800 feet (1500 m) and is underlain by tough granophyre and felsic volcanic rocks, and relatively weak granular-textured granite. The maximum relief within the Chain Lakes massif (2200 feet; 670 m), composed entirely of resistant gneisses and granofels, is substantially less, even though the region has apparently received a much greater amount of uplift. Areas predominately underlain by weak slates may exhibit relief of only a few hundred feet, such as the Central

TABLE 1. RELATIVE RESISTANCE OF ROCK TYPES EXPOSED IN MAINE AND RELATED PHYSIOGRAPHIC FEATURES. EXAMPLES OF REPRESENTATIVE FORMATIONS AND ROCK UNITS ARE PRESENTED IN ITALICS.

HIGH RELIEF	1	FELSIC VOLCANICS Traveler Range Mount Kineo Big Spencer Mountain *Traveler rhyolite* *Kineo rhyolite Member of the Tomhegan Fm.*	GRANOPHYRE, APLITE, etc. Mount Katahdin Catheart Mountain *Summit facies of the Katahdin pluton* *Cathedral facies of the Katahdin pluton* *Quartz porphyry and aplitic facies of the Attean pluton*	HORNFELS & GRANOFELS Big Squaw-Ragged Mountain Range White Cap Mountain Jo-Mary Mountain Saddleback Mountain Big Squaw Mountain Bigelow Range Onawa Range Oakfield Hills *Seboomook Fm.* *Carrabassett Fm.*
HIGH RELIEF	2	GNEISS & GRANOFELS Kibby Mountain Snow Mountain Caribou Mountain *Chain Lakes massif*	METASANDSTONES Misery Ridge Coburn Mountain Charlestown Ridge *Tarratine Fm.* *Madrid Fm.*	ANDESITE & BASALT Lobster Mountain Little Spencer Mountain Chase Mountain Range *Lobster Mountain volcanics*
LOW RELIEF	3	GRANITES (including quartz monzonite) Katahdin Lowlands Flagstaff Lake Richardson and Mooselookmeguntic Lakes Attean Basin	*Doubletop Facies of the Katahdin pluton* *Flagstaff Igneous Complex* *Attean quartz monzonite (coarse-grained facies)*	
LOW RELIEF	4	GABBRO AND ULTRAMAFIC PLUTONS *Moxie pluton (troctolite-diorite)*		
LOW RELIEF	5	SLATES Seboomook Fm. Tonhegan Fm. Carrabassett Fm. Allsbury Fm. Kennebec Fm. Dead River Fm. Quimby Fm.	single cleavage (most Devonian slate) multiple cleavages (pre-Silurian and most Silurian slates)	Northern Maine Lowlands Moose River Valley Moosehead Lake (North Bay) Central Lowlands Kennebec Valley Rangeley Lake
LOW RELIEF	6	MÉLANGE (scaly matrix) Hurricane Mountain mélange Moosehead Lake (Spencer Bay)	Kennebec Valley (Indian Pond)	

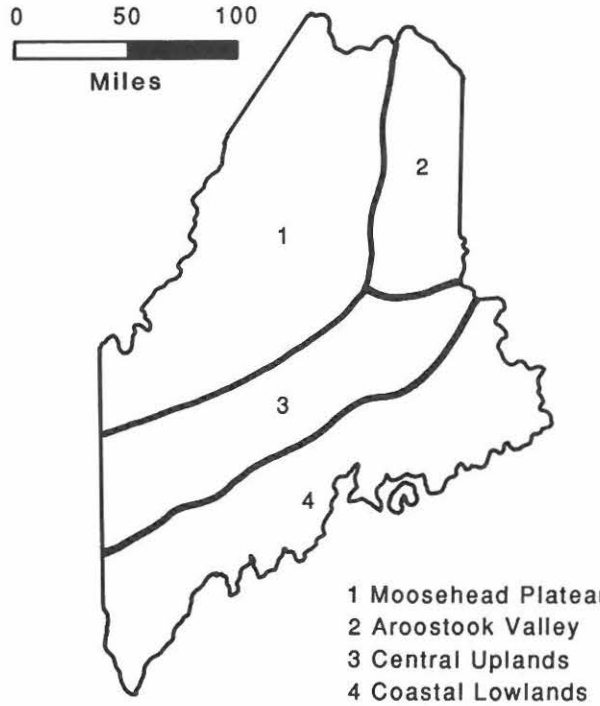


Figure 1. Physiographic subdivisions of Maine according to Toppan (1935). The average elevation of each division, as defined by Toppan, is as follows: (1) the Moosehead Plateau, 1000 feet (305 m); and (2) the Aroostook Valley, 700 feet (213 m); (3) the Central Uplands, 500 feet (152 m); (4) the Coastal Lowlands, 100 feet (30 m).

Maine Lowlands and much of the Northern Maine Lowlands (defined in the following section).

Previous Work

Toppan (1932, 1935) classified the physiographic divisions of Maine (Fig. 1) in terms of erosion surfaces defined by average land elevation. He stated that with very few exceptions, differences in land elevation were unrelated to bedrock geology. According to Toppan, his Central Uplands (see Fig. 1) are an uplifted, eastward dipping peneplain, composed "almost entirely of resistant metamorphic rock." Toppan's Moosehead Plateau (Fig. 1), having an average elevation of 1000 feet (300 m), was considered to be a deeply eroded Tertiary peneplain, with an "eroded escarpment" separating the plateau from the Central Uplands. While recognizing that the escarpment paralleled the regional strike, Toppan was unable to explain its origin. We find that, in part, this prominent topographic feature marks the transition from resistant hornfels to greenschist facies slates and sandstones. The hornfels delineates the western limb of the Kearsarge - central Maine synclinorium where Upper Silurian - Lower Devonian pelitic rocks, principally the Carrabassett Formation, were intruded by Acadian plutons. Espenshade and Boudette (1967) discussed the belt of hornfels that bordered the Moxie pluton and demonstrated that the higher elevations were controlled by the resistance of the hornfels, while plutonic rocks underlie the valleys and low hills in the area (Hanson and Caldwell, 1983; Caldwell and Hanson, 1987). Griscom (1976), Hon (1980), and Rankin and Hon (1987) have discussed the origin of the relief within the Katahdin pluton.

Denny (1980) presented a generalized geomorphic classification of New England (Fig. 2) in which he related topography to rock type and structure. However, the scale at which he worked (1:1,000,000) prevented any detailed analysis. The geomorphic classification presented here is based upon a more detailed analysis of local topography as determined by bedrock structure and lithology.

Physiographic Provinces and Regional Context

The geomorphic provinces defined in this paper are illustrated in Figure 3. Underlying lithology and structure along with topography form the basis of these divisions. Although each

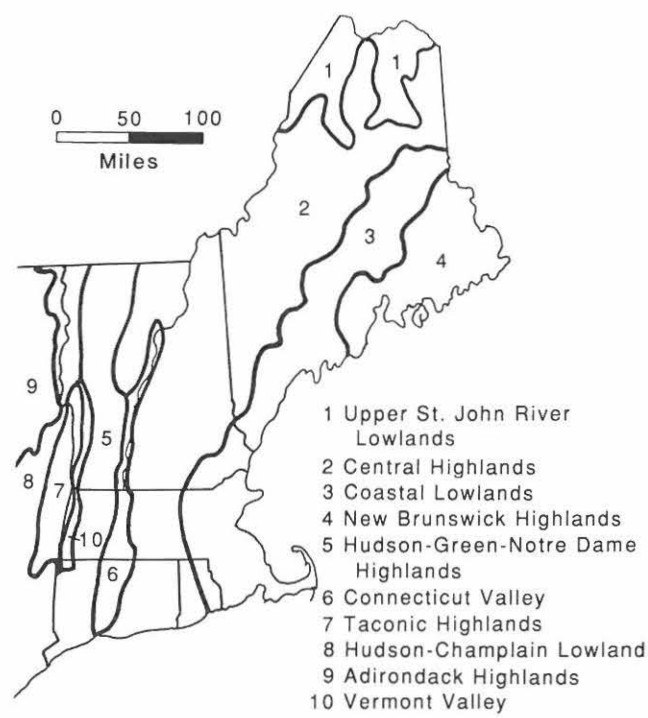


Figure 2. Denny's (1980) classification of the physiographic provinces of New England. Denny noted that topography of the Central Highlands was associated with more resistant and generally higher grade metasedimentary rocks than the lowlands in northern Maine (Upper St. John River Lowlands) and in the interior (Coastal Lowlands). Provinces are defined on the basis of watershed boundaries and topography and not underlying geology.

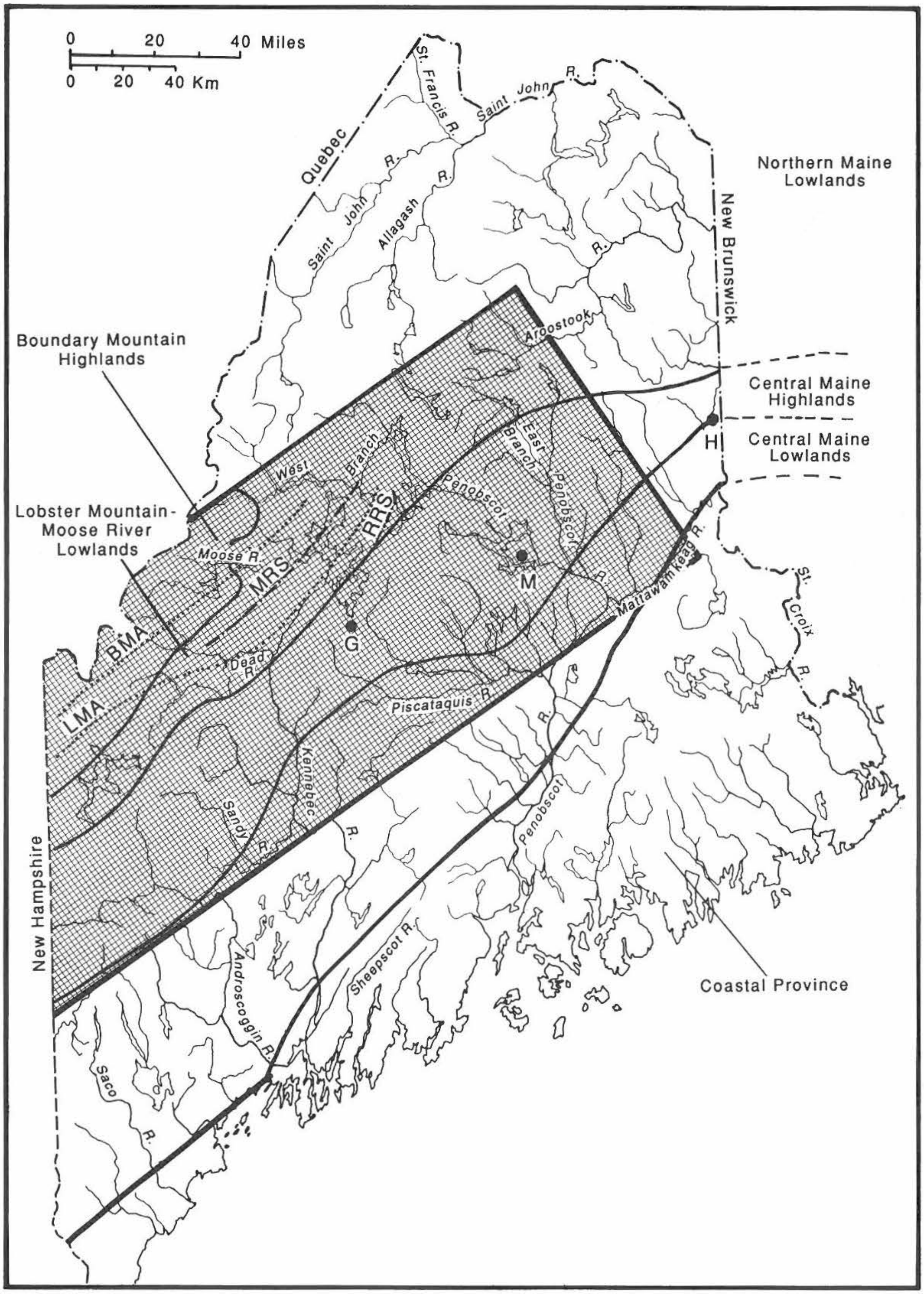


Figure 3. Physiographic subdivision of Maine defined in this report. Underlying structure and lithology along with topography form the basis of these divisions. The rectangular area outlines the area discussed in detail. The letters G, M, and H locate the towns of Greenville, Millinocket, and Houlton, respectively. Major anticlines (dotted) and synclines (dashed) referred to in text are, from west to east, the Boundary Mountains anticlinorium (BMA), Moose River synclinorium (MRS), Lobster Mountain anticlinorium (LMA), and the Roach River synclinorium (RRS).

province will be discussed briefly, only those of central Maine (rectangle in Fig. 3) will be discussed in detail.

The *Central Maine Highlands*, the most mountainous province in Maine, extend from the New Hampshire border through the Rangeley Lakes region, and continues 200 miles northeastward towards the New Brunswick border, near Houlton. The highlands lie almost entirely within the northwestern margin of the Kearsarge - central Maine synclinorium (Lyons et al., 1982), a broad belt of regionally-deformed, Silurian through Lower Devonian, deep-water sediments which have been locally intruded and contact metamorphosed by Upper Silurian (?) through Devonian plutons (Espenshade, 1972; Espenshade and Boudette, 1967; Boone, 1970, 1973; Vehrs, 1975; Hanson, 1988). Mean elevation of the highlands belt, along with metamorphic grade and depth of erosion, progressively decreases towards the northeast. Topography is strongly related to the regional structure and the occurrence of plutons.

The *Boundary Mountains Highlands*, along the northwestern Maine border near Quebec, contain the southwestern portions of the Boundary Mountains and Lobster Mountain anticlinoria (Albee, 1961). As the northern extension of the Bronson Hill anticlinorium to the south, these belts are composed of pre-Silurian basement rocks that were accreted to the North American margin during the Taconic orogeny. An irregular, random topography has been developed on the crystalline rocks underlying most of this province. The mountainous areas are composed of resistant gneisses or granofels, hornfelsic and volcanic rocks, and fine-grained plutonic rock (Albee and Boudette, 1972; Boone, 1970; Boudette and Boone, 1976) while basins are largely underlain by coarser-grained plutonic rocks.

The *Northern Maine Lowlands*, the largest province, are characterized by predominantly low-grade (prehnite-pumpellyite and greenschist facies), Cambrian through Middle Devonian metasedimentary and volcanic rocks (Richter and Roy, 1976; Osberg et al., 1985). Topography reflects the excavation of fold belts of predominantly pelitic rocks, uncomplicated by Devonian intrusions.

The *Lobster Mountain - Moose River Lowlands*, discussed here in detail, can be considered a southwesterly-trending arm of the Northern Lowlands, beginning along the Penobscot - Kennebec drainage divide (Fig. 7) and terminating just beyond the New Hampshire border. Located between the Boundary Mountains Highlands and the Central Maine Highlands, the Lobster Mountain - Moose River Lowlands are underlain by the Lower Devonian metasedimentary and volcanic rocks of the Moose River synclinorium (Boucot, 1961; Boucot and Heath, 1969) and the pre-Silurian mélange, phyllite, and volcanic rock of the Lobster Mountain anticlinorium (Boone, 1983; Osberg et al., 1985). The lowlands are divided by a long, continuous ridge of Devonian quartzite and volcanic rocks. The ridge and adjacent valleys resemble, but on a much smaller scale, the Valley and Ridge Province of the middle Appalachians. The southern tip of the province is the only portion underlain by igneous and high-grade metamorphic rocks.

The *Central Maine Lowlands* and *Coastal Province* are largely outside of the study area, but will be summarized briefly here. The Central Maine Lowlands occupy the axis and southern margin of the Kearsarge - central Maine synclinorium and portions of the Aroostook - Matapedia belt. Excluding the southern portion, this province is largely underlain by tightly folded and relatively weak slate, phyllite, metasandstone, and limestone. The weak underlying rocks account for the region's extremely low relief, rarely exceeding one hundred feet. Highlands are locally ridges of more resistant sandstone (e.g. Madrid Formation) or irregular hills related to contact metamorphism. Local intrusions largely postdate Acadian folding and abruptly truncate structural belts, in contrast to the Central Maine Highlands where fold belts often appear to be deflected near plutons. Contact aureoles are also less well defined by topography, forming hills and low mountains with peaks generally less than 1500 feet. This, in part, may be a function of the host rock composition (i.e. sandstones, limestones and/or conglomerates instead of pelite-rich rocks) and prior metamorphic history.

Topography of the Coastal Province has developed on metasedimentary and plutonic rocks of the Avalon Terrane. Greater than fifty percent of the province is underlain by plutonic rock and is characterized by multibasinal drainage systems. Most streams east of the Penobscot River are developed in plutonic rocks and have strong southward orientations. This orientation most likely reflects the preferred excavation of joints that paralleled the direction of dominant glacial flow in the Pleistocene. Streams west of the Penobscot River flow through metasediments and exhibit a southwestward trend, parallel to regional faults and structural strike. North of the Saco River, the coastline is highly indented, containing numerous linear embayments. The smooth and arcuate shoreline to the south can be attributed to the parallel orientation of the regional structure with the shore, less intense glacial excavation, and a greater availability of sediment provided by streams and deposits of glaciomarine sands. Proximity of the Sebago pluton may also influence the volume of sediment provided to the southern Maine coast. Like most Maine plutons, the Sebago pluton, subject to rapid granular disintegration, was a great producer of sand during late Wisconsinan glaciation (Thompson and Borns, 1985).

CENTRAL MAINE HIGHLANDS

Topography

In western Maine, the Central Maine Highlands are more than 45 miles (73 km) wide. The province narrows toward the northeast to less than 10 miles (16 km) near the Oakfield Hills. Several mountain ranges comprise the Central Maine Highlands. From west to east they are the: Mahoosuc Range, Blue Range (Longfellow Range), Bigelow Range, Squaw Mountain - Ragged Mountain Range, Onawa Range, Katahdin and Traveler Ranges, Chase Mountain Range, and Oakfield Hills (Fig. 4).

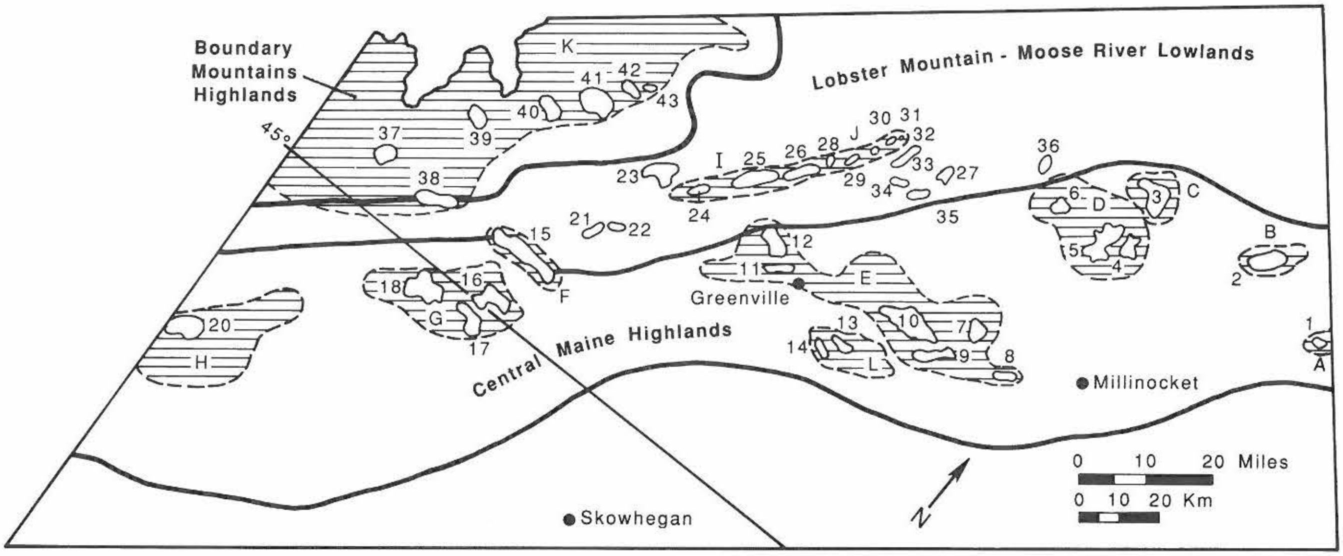


Figure 4. Mountain ranges of north-central Maine. Numbers refer to individual mountain ranges and their names and elevations are listed in Table 2.

With the exception of the Katahdin region, there is a regional increase in summit elevations toward the southwest into New Hampshire, where several peaks in the Presidential Range exceed 5000 feet (1524 m). Although Mt. Katahdin at 5268 ft (1606 m) is the highest in Maine, there is a greater number of high peaks (those exceeding 4000 feet; 1219 m) in the southwestern portion of the highlands. In fact, with the exclusion of Katahdin and North Brother (4143 ft; 1263 m), all other high peaks in Maine are found to the southwest (Fig. 4; Table 2). These include Sugarloaf (4237 ft; 1291 m), Old Speck Mountain (4180 ft; 1274 m), Bigelow Mountain (4150 ft; 1265 m) Saddleback Mountain (4116 ft; 1255 m), and Mount Abraham (4049 ft; 1234 m). There is a gap of more than 80 miles (128 km), between Bigelow Mountain and Mount Katahdin, in which there are no mountains that exceed 4000 feet (1219 m) in elevation. The increase in elevation toward the southwest is illustrated in the generalized map of altitudes shown in Figure 5. When the higher peaks across the border in the White Mountains of New Hampshire are included, this trend becomes even more striking.

Many earlier workers have attempted to explain this trend in summit elevations. Toppan (1935) believed the regional decrease in elevation toward the northeast was related to a dissected sloping erosion surface. Goldthwait (1914) believed that the so-called Presidential Peneplain extended from the higher summits in the White Mountains, across many of the high peaks of the Central Maine Highlands, to the Tableland of Mount Katahdin. As will be discussed later, evidence suggests that differential uplift, resulting in a southwest-to-northeast tilting of the Acadian orogen, occurred in the late Paleozoic and/or Mesozoic. This regional tilting is most likely responsible for the observed trend in summit elevations.

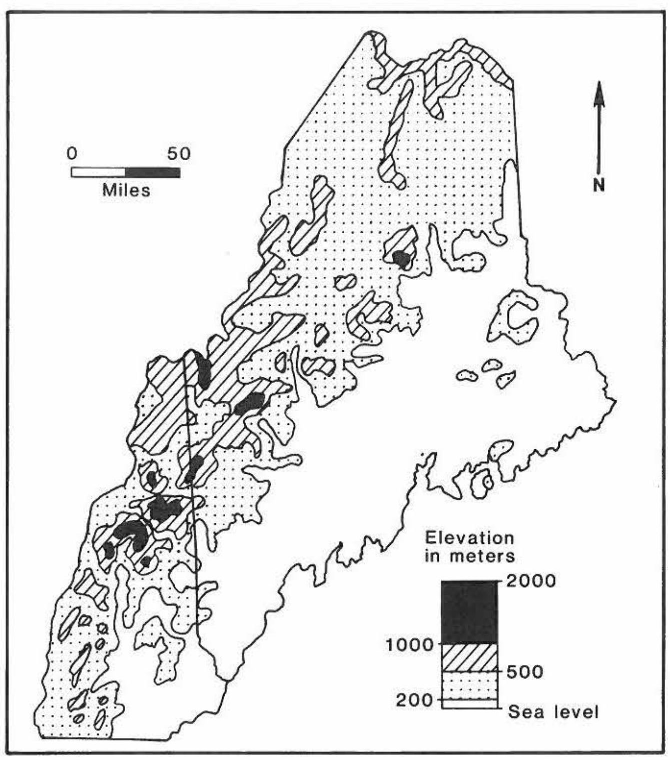


Figure 5. Generalized hypsometric map of Maine and New Hampshire (modified from Denny, 1980). This map illustrates the regional increase in elevation and upward tilt toward the southwest into the White Mountains. Associated with the increasing elevation is a higher regional metamorphic grade and greater depth of excavation.

TABLE 2. MOUNTAIN RANGES AND SUMMIT ELEVATIONS FOR MOUNTAINS IN CENTRAL AND WESTERN MAINE. SEE FIGURE 4 FOR LOCATIONS.

CENTRAL MAINE HIGHLANDS		
A. OAKFIELD HILLS		
(including neighboring mountains)		Feet
1	Robinson Mountain	1026
B. CHASE MOUNTAIN RANGE		
2	Chase Mountain	2440
C. TRAVELER RANGE		
3	Traveler Mountain	3541
	Center Mountain	2902
D. KATAHDIN RANGE		
4	Turner Mountains	
	North Turner	3323
	South Turner	3122
5	Katahdin (Baxter Peak)	5268
6	Doubletop	3600
	North Brother	4143
	Coe	3764
	OJI	3520
E. BIG SQUAW - RAGGED MOUNTAIN RANGE		
7	Jo-Mary Mountain	2904
8	Ragged Mountain	1303
9	Saddleback Mountain	2998
	Big Wilkie	1650
	Little Wilkie	2093
10	White Cap Range	
	White Cap Mountain	3707
	Big Shanty Mountain	2800
	Little Shanty	3152
	Big Spruce Mountain	3104
11	Little Squaw Mountain	2140
12	Big Squaw Mountain	3190
L. ONAWA RANGE		
13	Barren Mountain	2671
14	Boarstone Mountain	1960
F. BIGELOW RANGE		
15	Bigelow Mountain	4150
G. BLUE (LONGFELLOW) RANGE		
16	Sugarloaf Mountain	4237
17	Mount Abraham	4049
18	Saddleback Mountain	4116
H. MAHOOSUC RANGE		
20	Old Speck Mountain	4180

LOBSTER MOUNTAIN - MOOSE RIVER LOWLANDS		
LOBSTER MOUNTAIN ANTICLINORIUM		
21	Hurricane Mountain	3825
22	Dead River Mountain	2000
33	Lobster Mountain	2280
34	Little Spencer Mountain	2990
MOOSE RIVER SYNCLINORIUM		
I. TARRATINE RANGE		
23	Coburn Mountain	3710
24	Cold Stream Mountain	2520
25	Misery Ridge	2128
26	Blue Ridge	1877
J. KINEO RANGE		
26	Blue Ridge	1877
28	Mount Kineo	1806
29	Little Kineo	1927
30	Eagle Mountain	1685
31	Norcross Mountain	1616
ROACH RIVER SYNCLINORIUM		
27	Black Cap Mountain	1963
35	Big Spencer Mountain	3230
NORTHERN MAINE LOWLANDS		
36	Soubunge Mountain	2104
BOUNDARY MOUNTAINS HIGHLANDS		
K. BOUNDARY MOUNTAINS		
37	West Kennebago Mountain	3705
38	Kennebago Mountain	3825
39	Snow Mountain	3948
40	Kibby Mountain	3538
41	No. 5 Mountain	3168
42	Attean Mountain	2442
46	Sally Mountain	2221
47	Catheart Mountain	2281

Geology

Rocks of the Central Maine Highlands are predominantly Silurian and Lower Devonian pelitic metasedimentary assemblages that were deformed and intruded during the Early Devonian Acadian orogeny. Nearly all of the high peaks southwest of the Katahdin - Traveler Range are held up by hornfelsic rock, or high-grade metamorphic rocks lacking a well developed schistosity or pervasive cleavage. Within the Katahdin - Traveler Range and to the north, most peaks are held up by volcanic rock, granophyre, and/or hornfels.

Topography Related to Contact Metamorphism. Many mountain ranges in the Central Maine Highlands are composed of hornfelsic turbidite strata of a predominantly pelitic composition (Fig. 4; Tables 1 and 2). The strong interlocking texture makes these rocks more resistant than their foliated, regionally-metamorphosed counterparts which are inherently less resistant (Fig. 6).

The height and width of a contact aureole is controlled by the temperature and dimensions of the pluton, water content, composition and temperature of the country rock, depth of intrusion, and the orientation and position of the pluton relative

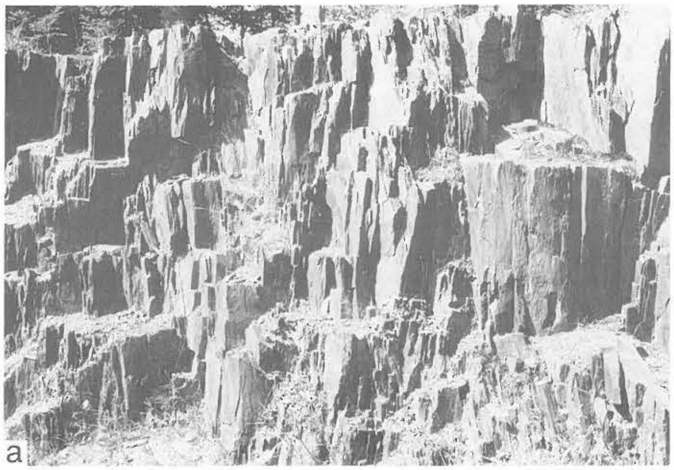


Figure 6 a. Slates of greenschist facies metamorphic grade exposed on Route 15 south of Greenville. Slates are pervasively cleaved and therefore inherently weak. Broad lowlands are developed where large tracts of slate are exposed, such as the broad belt of Ordovician (?) through Lower Devonian slates of the Central Lowlands.

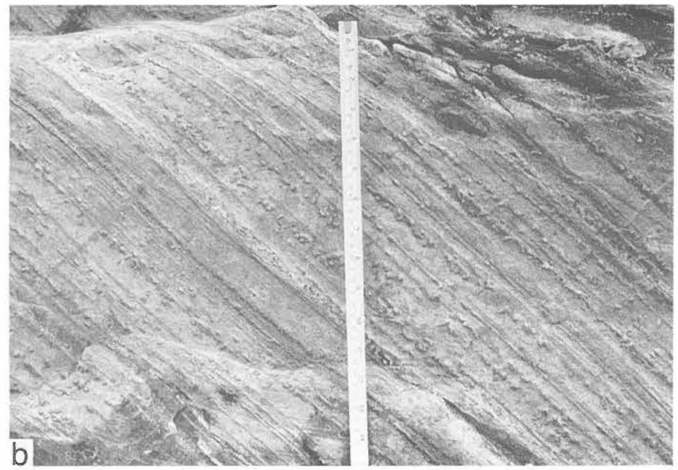


Figure 6b. Hornfelsic equivalent of rocks shown in Figure 6a; here exposed west of Greenville along Routes 15 and 6. This resistant lithology has a durable, interlocking granoblastic texture, and contains varying amounts of cordierite, sillimanite, andalusite, quartz, mica (primarily biotite), and feldspar (Espenshade and Boudette, 1967). Inherent planes of weakness, such as bedding or cleavage planes have been annealed or are lacking.

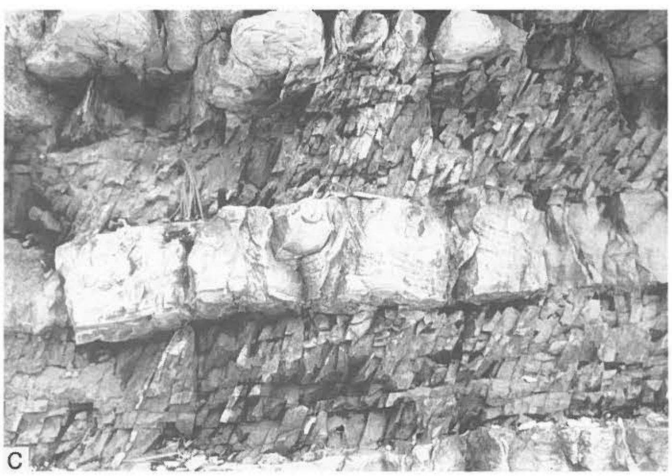


Figure 6c. Similar rocks exposed on Harrington Lake (northwest of Millinocket), mapped as Seboomook Formation by Griscom (1976). These argillaceous rocks, located close to the margin of the Katahdin pluton, show very little contact metamorphism and do not demonstrate the well developed slaty cleavage seen in Figure 6a. However, these rocks do exhibit "pencil structure" (Reks and Gray, 1982) where the intersection of bedding with cleavage results in the formation of elongate microlithons. This type of structure characteristically forms along fold axes. This rock is easily eroded.

Figure 6. Effects of deformation and metamorphism on the resistance of pelitic rocks, in this case, some Lower Devonian thin-bedded turbidites of the Carrabassett (a and b) and Seboomook (c) Formations.

to the country rock. Thick, inclined, sheet-like plutons have wider aureoles on the "headwall" side of the intrusion than on the underside, especially in cases associated with water-rich magmas. Guidotti et al. (1986) have demonstrated in their study of the Carboniferous Sebago pluton (located in the Central Lowlands) that there is a higher grade of regional metamorphism (sillimanite and K-feldspar grade) closely related to thermal effects on the northern rim of the northward dipping tabular intrusion. Along the southern side of the pluton the rocks reach only sillimanite grade (Guidotti et al., 1986). This difference in metamorphism is related to the ease with which fluids can move upward as compared to moving downward (Guidotti et al., 1986).

In the northern half of the Central Maine Highlands, where adjacent metasedimentary rocks are commonly weak slates or phyllites, the relationship between topography and thermal metamorphism is clearly visible; hornfels forms highlands and adjacent slaty rocks form lowlands. However, these relationships become less noticeable in the higher grade terrain to the south. Multiple intrusive events coupled with higher grade regional metamorphism have produced granofels, porphyroblastic schists, and gneisses, many of which are highly resistant. The sharply contrasting topography, such as that affiliated with slate-hornfels associations clearly seen farther north, does not exist or is less obvious in regions of high-grade metamorphism.

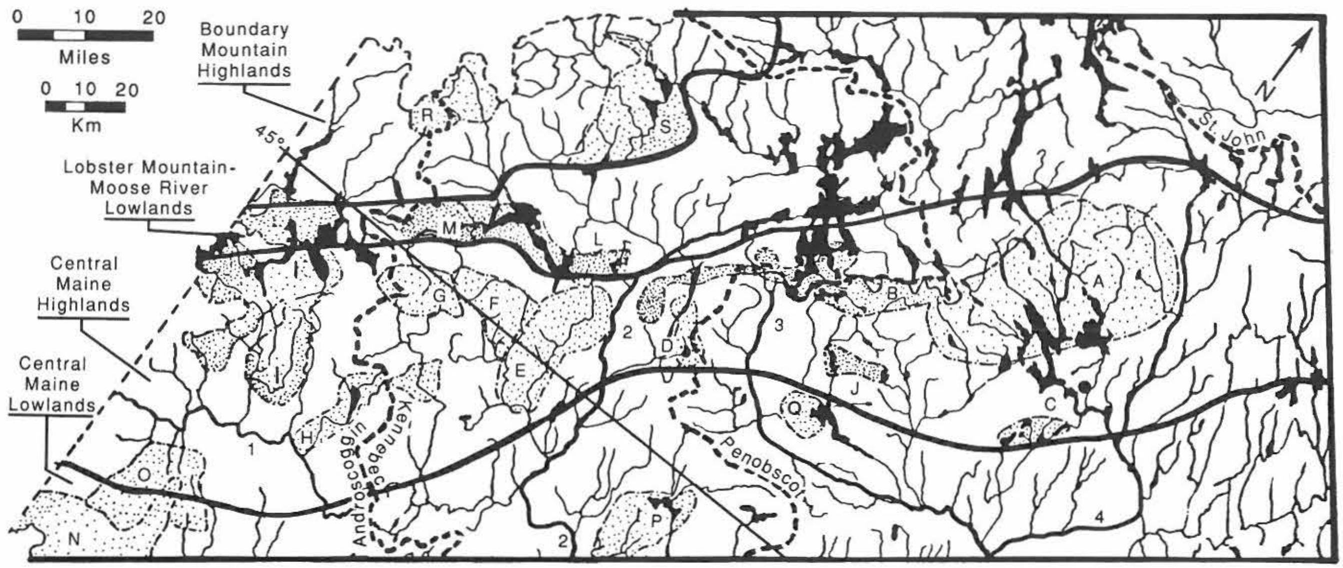


Figure 7. Location of lake basins relative to plutons. With very few exceptions, lowland regions in Maine tend to be underlain by either low-grade metapelitic rocks or plutonic rocks. In the Northern Lowlands, basins are underlain by slate or phyllite. However, in the Central Maine Highlands, lake basins are invariably related to plutonic rocks. The key to plutons and some of the lakes which occur within them are given in Table 3. Major river basins are shown by heavy dotted lines.

When not associated with highly cleaved metasedimentary rocks, broad lowlands within the Central Maine Highlands, which are commonly occupied by lakes, are invariably underlain by plutonic rock (Fig. 7). Although many lowlands here are supported by plutons, not all intrusive rocks form lowlands. This apparent contradiction occurs because most plutons are not texturally homogeneous. A pluton may have been protected by resistant cap rock, such as a recently removed hornfelsic roof pendant. Also, finer grained, more resistant border facies commonly are associated with margins of plutons. As erosion proceeds from the top of the pluton outward, the center of the pluton is exposed first and is rapidly excavated. The perimeter of the pluton, composed primarily of more resistant border facies, are the last to go and may form highlands adjacent to the hornfels. A good example of this relationship occurs near the summit of Big Squaw Mountain, where fine-grained border facies of the Moxie pluton is in contact with injection hornfels. These relationships are illustrated with other specific examples in the following section.

Highlands in the Contact Aureoles of the Moxie and Related (?) Plutons. Highlands composed of hornfelsic rock are commonly irregular and broadly encompass equally irregular basins underlain by plutonic rock. The Big Squaw - Ragged Mountain Range is a good example of the variable shapes and sizes of these mountains (Fig. 8). In Greenville, the width of the range is closely controlled by the width of the Moxie pluton, which varies from 1.5 to 6 miles (2.5 to 10 km). The widest portions of the pluton are bulb-shaped and are associated with broad hornfels highlands, as at Big and Little Squaw Mountains. Hon and Schulman (1983) believe these bulb-shaped emanations in the Moxie pluton may have led to overlying volcanic centers.

Figure 8. Irregular topography typical of mountainous regions underlain by hornfelsic and plutonic rocks. These hornfels mountains comprise a portion of the Big Squaw - Ragged Mountain Range and are associated with the mafic Moxie pluton. This southeasterly view of the range, from Moosehead Lake, shows a broad lowland in the foreground, occupied in part by the Moxie pluton. The first hornfels ridge is Prong Pond Mountain. The White Cap Range lies in the background, and a valley, underlain by a portion of the Moxie pluton, separates the two highlands.

Therefore, these areas stayed hotter for a longer period and acted as conduits for more water-rich phases than the thinner portions of the pluton. Width of the highland may also be influenced by the dip of the pluton. Geophysical surveys and asymmetrically-

TABLE 3. LAKES ASSOCIATED WITH PLUTONS IN CENTRAL AND WESTERN MAINE. SEE FIGURE 7 FOR LOCATIONS.

CENTRAL MAINE HIGHLANDS	
A. KATAHDIN PLUTON	Feet
Millinocket Lake	478
Ambajejus Lake	492
Pemadumcook Lake	492
Jo-Mary Lake	493
Upper Jo-Mary Lake	525
Rainbow Lake	1046
Nahmakanta Lake	646
Katahdin Lake	1022
W. Branch Penobscot River (Dolby Pond)	335
B. MOXIE PLUTON	
Moosehead Lake (eastern margin)	1029
Upper Wilson Pond	1123
Prong Pond	1030
C. SEBOEIS LAKE - SCHOODIC PLUTON	
Seboeis Lake	438
Schoodic Lake	429
Endless Lake	411
D. BALD MOUNTAIN PLUTON	
Austin Pond	1184
Bald Mountain Pond	1213
E. LEXINGTON PLUTON	
F. SUGARLOAF	
G. READINGTON PLUTON	
H. PHILLIPS PLUTON	
I. MOOSELOOKMEGUNTIC & UMBAGOG PLUTONS	
Mooselookmeguntic Lake	1467
Upper and Lower Richardson Lakes	1448
Umbagog Lake	1245
J. ONAWA PLUTON	
Lake Onawa	537
Indian Pond	
LOBSTER MOUNTAIN - MOOSE RIVER LOWLANDS (plutons restricted to the southern end of the Lobster Mountain anticlinorium)	
L. PIERCE POND GABBRO	
Pierce Pond	1142
M. FLAGSTAFF LAKE IGNEOUS COMPLEX	
Flagstaff Lake	1146
South Branch Dead River	2000-1146
BOUNDARY MOUNTAINS HIGHLANDS	
R. SPIDER LAKE PLUTON	
S. ATTEAN PLUTON	
Attean Basin	
Attean Pond	1159
Wood Pond	1159
Holeb Pond	1231
No. 5 Bog	1190
CENTRAL MAINE LOWLANDS	
Q. SEBEC PLUTON	
Sebec Lake (west End)	322
P. HARTLAND PLUTON	
Great Moose Lake	245
O. SONGO AND SEBAGO PLUTONS	
Sebago Lake	267

dipping igneous laminations indicate that the Moxie pluton dips toward the southeast (Hon, pers. commun., 1987).

The contact aureole related to the Katahdin laccolith is variable and commonly poorly defined by topography. Unlike the Moxie pluton, there is not a high hornfels rim surrounding the Katahdin granite. Where the granite intrudes the Seboomook Formation at Harrington Lake there is very little to no contact aureole. This is somewhat of an enigma considering the size of the pluton. However, the edge of the laccolith may have been quite thin along the northwest margin. Also, the pluton was emplaced at a temperature only slightly greater than 700°C (Hon, 1980), which may not have been high enough to develop an extensive aureole.

Along the southeastern margin of the Katahdin pluton lies a belt of hornfels that is over four miles wide. This belt contains such mountains as White Cap Mountain, Big and Little Shanty Mountains, Big and Little Spruce Mountains, Saddleback Mountain, Big and Little Wilkie Mountains, Jo-Mary Mountain, and Ragged Mountain. All lie within the northeastern half of the Big Squaw - Ragged Mountain Range. The contact of the Katahdin pluton with the country rock (largely of the Carrabassett Formation) is characterized by a tract of migmatite containing local diorite bodies (Hanson, 1988). These diorite bodies suggest that the Katahdin pluton may not have been entirely responsible for the extensive belt of hornfels found along its southeastern margin. Instead, they may attest to the incipient unroofing of a larger underlying, southeasterly-dipping mafic body, such as that exposed to the southwest where the level of erosion is deeper and where the Moxie pluton has been entirely unroofed. Migmatite and injection hornfels, similar to that seen in the Jo-Mary Mountain area, is exposed in rocks overlying and adjacent to the Moxie pluton on Big Squaw Mountain.

The Onawa pluton is a diorite (Philbrick, 1936), probably related to the Moxie pluton, that has developed a well defined contact aureole. The pluton itself underlies a large basin occupied in part by Onawa Lake and surrounded by very steep mountains, such as Borestone, Barren, Columbus, Chairback, and Benson Mountains. The steep cliffs on Borestone and Barren Mountains (Fig. 9), overlooking the basin of Onawa Lake, suggest that the pluton is a stock having nearly vertical contacts with the surrounding country rock.

Plutonic and Volcanic Massifs. With few exceptions, mafic and intermediate phaneritic rocks form lowlands because of their lower relative resistance compared to surrounding hornfels or fine-grained border facies. Minerals associated with mafic rocks (e.g. pyroxene, plagioclase, amphibole, etc.) are highly receptive to chemical weathering and as a result, the rocks undergo rapid granular disintegration or spheroidal weathering (Goldich, 1938). In Greenville, the chill zone of the Moxie pluton is composed of fine to medium-grained gabbro which weathers spheroidally. This finer-grained gabbro is apparently more stable than the coarse-grained cumulate gabbro which formed within the interior of the pluton and which underlies the lowest portion of the Moxie trend. Fine-grained gabbro in contact with

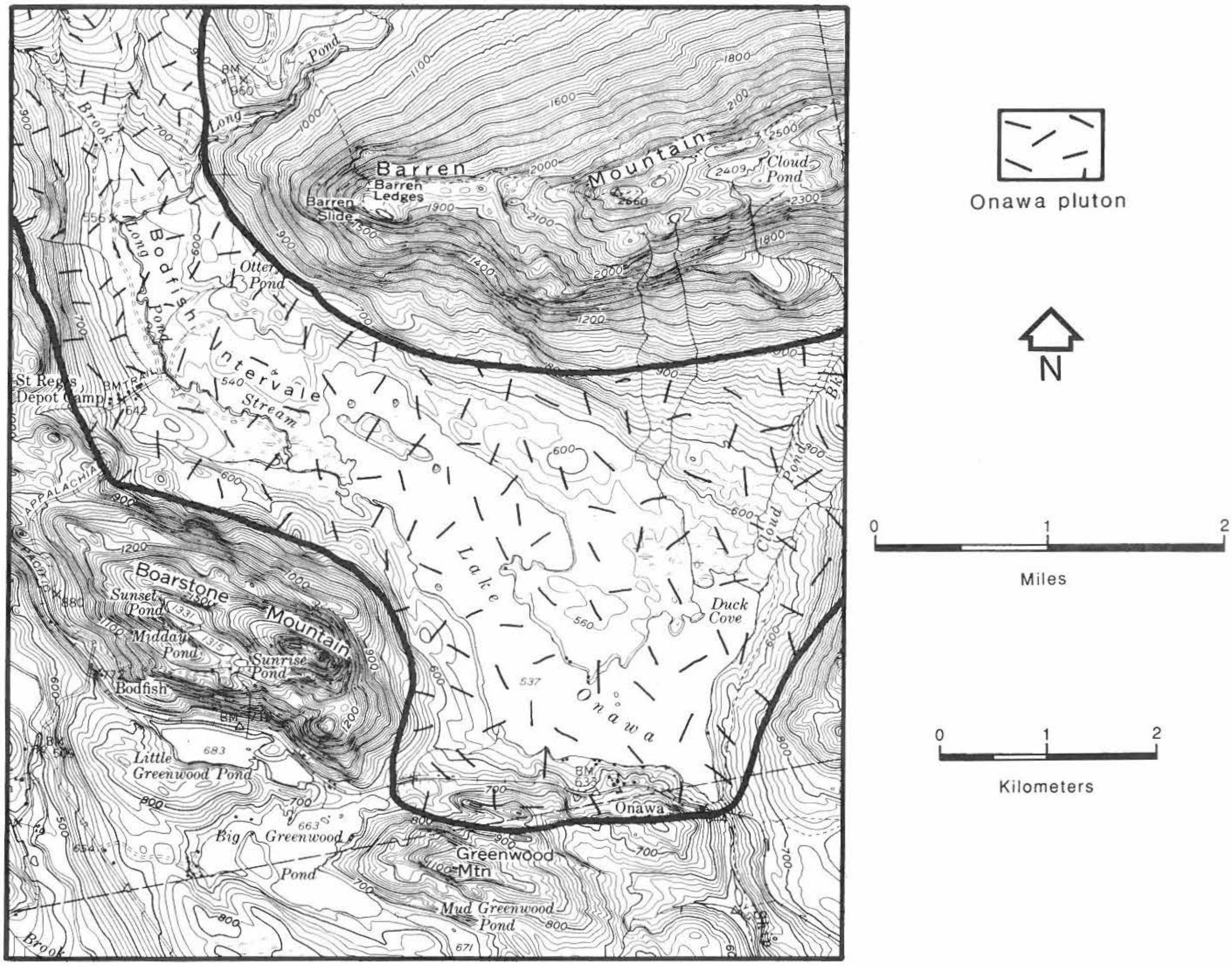


Figure 9. The relative resistance exhibited by hornfels, slate, and plutonic rock is illustrated in this region surrounding and overlying the Onawa pluton. The lowland containing Lake Onawa and Bodfish Intervale is underlain by deeply weathered diorite. The surrounding steep ridges are hornfels and migmatite produced in the Carrabassett Formation. The low-lying area occupied by Big Greenwood Pond in the southwest corner of the map is underlain by slates and thin-bedded sandstones of the same formation.

metasedimentary rocks on Big Squaw and Trout Pond Mountains attests to a greater resistance and possibly also to a more recent unroofing.

Differences in the style and relative rates of weathering in igneous rocks of the same composition are a function of the complexity of grain sutures. Euhedral to subhedral crystals have straight boundaries and are commonly associated with the coarser phaneritic rocks. In fine-grained rocks, in particular granophyric rocks, grains are commonly anhedral and complexly intergrown, forming a highly resistant texture.

Variations in resistance related to texture are well illustrated in the Katahdin pluton, a large granitic laccolith having an exposed area of approximately 800 mi^2 (2000 km^2). Most of the pluton forms low hills, lake basins, and river valleys with an average elevation of about 1000 feet (Hon, 1980; Caldwell and Hanson, 1987). However, Mount Katahdin, the highest mountain in Maine, and its surrounding peaks are also underlain by the same pluton. Thus, the Katahdin pluton has the highest local relief (approx. 4800 feet; 1463 m) of any rock body in Maine (Fig. 10a), and likely of any rock unit east of the Colorado Front Range.

The tremendous variation in elevation exhibited by the pluton can be related to the textural characteristics of the different granitic facies (Griscom, 1976; Hon, 1980; Rankin and Hon, 1987) within the pluton. The least resistant and most ubiquitous is the Doubletop facies, having a medium- to coarse-grained granular texture produced by slow cooling deep within the interior of the pluton. Grain boundaries are poorly sutured (Fig.

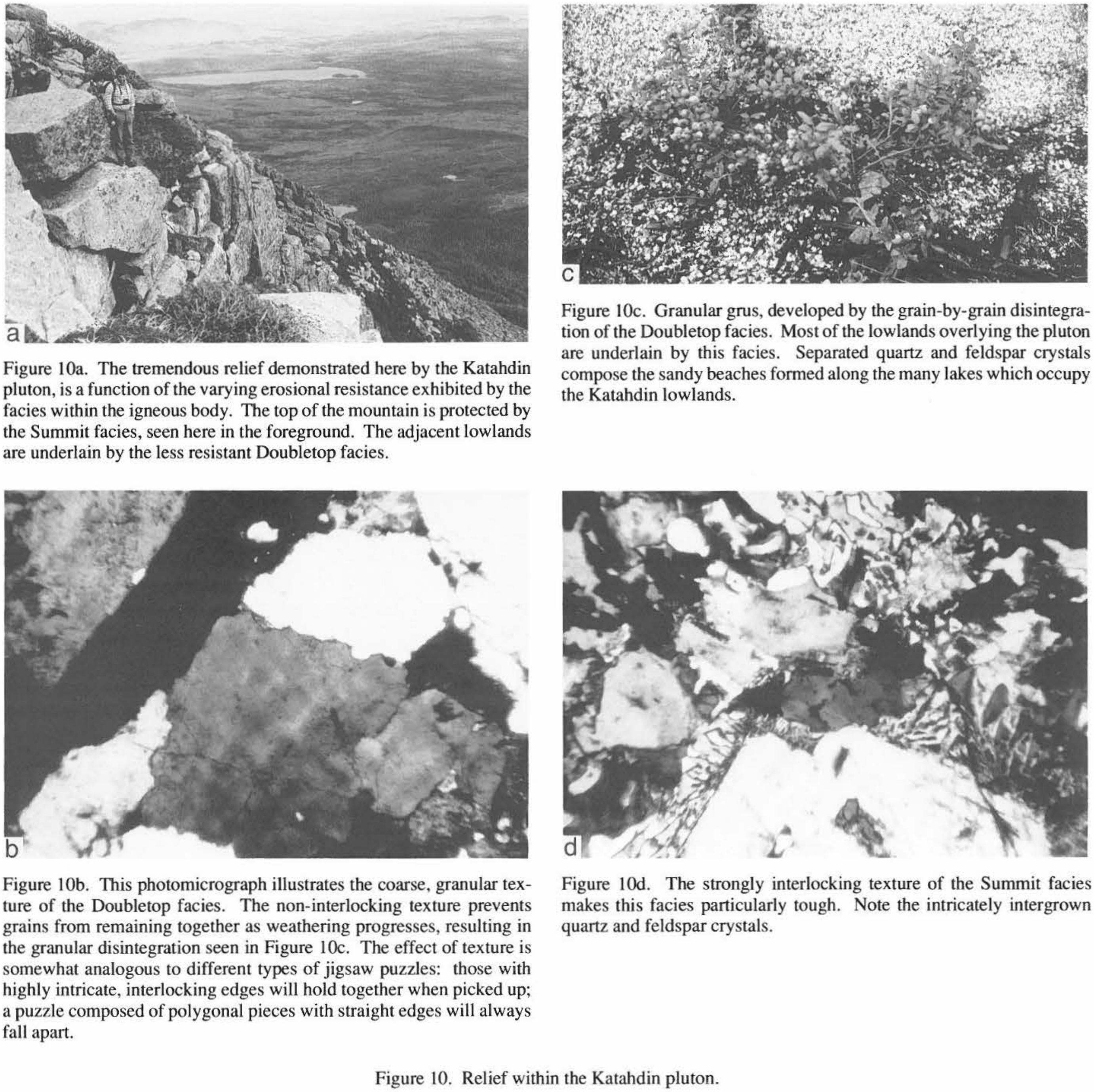


Figure 10a. The tremendous relief demonstrated here by the Katahdin pluton, is a function of the varying erosional resistance exhibited by the facies within the igneous body. The top of the mountain is protected by the Summit facies, seen here in the foreground. The adjacent lowlands are underlain by the less resistant Doubletop facies.

Figure 10c. Granular grus, developed by the grain-by-grain disintegration of the Doubletop facies. Most of the lowlands overlying the pluton are underlain by this facies. Separated quartz and feldspar crystals compose the sandy beaches formed along the many lakes which occupy the Katahdin lowlands.

Figure 10b. This photomicrograph illustrates the coarse, granular texture of the Doubletop facies. The non-interlocking texture prevents grains from remaining together as weathering progresses, resulting in the granular disintegration seen in Figure 10c. The effect of texture is somewhat analogous to different types of jigsaw puzzles: those with highly intricate, interlocking edges will hold together when picked up; a puzzle composed of polygonal pieces with straight edges will always fall apart.

Figure 10d. The strongly interlocking texture of the Summit facies makes this facies particularly tough. Note the intricately intergrown quartz and feldspar crystals.

Figure 10. Relief within the Katahdin pluton.

10b) and once exposed, the facies undergoes rapid granular disintegration (Fig. 10c).

Above the Doubletop facies, the granite grades into the uppermost Summit facies, a resistant granophyre. Granophyres are formed from the crystallization of chilled border phases of granitic plutons. As the top of the Katahdin laccolith was quenched against its overlying volcanic (Hon, 1980) and sedimentary cover, a glass was produced. Later devitrification of the chill zone produced the granophyre of the Summit facies. The intricately intergrown feldspar and quartz form a micrographic texture (Fig. 10d) which resists chemical and physical weathering.

Geomorphology of the Katahdin Massif. The broad Tableland of Mount Katahdin (Fig. 11) is in part analogous to a mesa where a less resistant underlying lithology, in this case the Doubletop facies, is protected by a more resistant cap rock. As

Figure 11. Panoramic view of the Katahdin laccolith taken from the northeast, near Oakfield Hills. The retreating south-facing slope is to the left. The arcuate surface reflects that of the laccolith and dips beneath Traveler Mountain to the far right (north).

Figure 13. Progressive stages of denudation of the Katahdin pluton are represented by the mountains in the foreground west of Mt. Katahdin. The rounded peak in the foreground (Mount O-J-I with the prominent slide scars) is the result of rapid slope decline following removal of the Summit facies. In the background, a more recent unroofing is indicated by the mountains exhibiting steeper slopes and pointed peak (Mount Coe behind Mount O-J-I, with North Brother to the left). Mount Katahdin lies to the right of the field of view.

Figure 12. View of a portion of the Tableland above the Saddle Slide. This apparently flat surface of Katahdin known as the "Tableland", was thought to have been an uplifted peneplain (Goldthwait, 1914; Toppan, 1935). Recent studies indicate that the surface is controlled by a resistant granophryric facies which borders the top of the laccolith.

Figure 14. Vertical expansion joints developed along the headwall of North Basin on Mount Katahdin are formed in response to the lateral removal of rock by late-glacial cirque glaciers.

viewed from the east (Fig. 12), the broadly curved upper surface of the laccolith is still discernible, but has been highly dissected on either side of Katahdin. Previous workers have described the origin of the Tableland as either the product of cryoplanation (Thompson, 1960) or as an uplifted peneplain (Goldthwait, 1914). The southeast slope of the mountain is undergoing parallel retreat and will continue to retreat northeastward until the summit facies is removed. Surrounding peaks (e.g. Doubletop, Coe, O-J-I, and North Turner Mountains) have recently been unroofed and have started a process of slope decline (Fig. 13). Recent unroofing of these mountains can be inferred from the fact that they are composed predominantly of Doubletop facies yet stand relatively high. In addition, the lower "contact" of the Summit facies can be projected to elevations just above the present peaks.

Continental glaciation of Mt. Katahdin has accelerated erosion by locally removing the Summit facies, such as along the Saddle. Vertical joints formed from lateral unloading along cirque headwalls, developed by alpine glaciation (Caldwell and Hanson, 1987), have promoted mass wasting which is rapidly eroding the mountain from the east (Fig. 14).

Nearly all of the Katahdin pluton south of Mount Katahdin underlies a lowland. Where the pluton has been deeply excavated, stream channels developed along conjugate joints and

Figure 15. Incipient drainage network developing along conjugate joints and faults within the Katahdin granite, south of Rainbow Lake. Streams developing along zones of weak rock can extend their channels more effectively than normal consequent streams. In plutons, which lack bedding planes and pervasive cleavage, fracture systems are the principle zones of weakness in which streams can carve channels. (Photo courtesy of Great Northern Paper Company)

faults are visible (Fig. 15). In plutonic rock, fracture zones are the principle lines of weakness along which streams can more readily extend their channels. In homogeneous, undeformed or poorly fractured plutons (e.g. Attean pluton), drainage systems are not controlled by structural elements and are commonly dendritic. Other plutons which form extensive lowlands in the Central Maine Highlands (Fig. 7; Table 3) are the Flagstaff Lake Igneous Complex, Lexington batholith, Pierce Pond gabbro, Seboeis pluton, Mooselookmeguntic and Umbagog plutons, and Rockabema pluton. The Sebago batholith, in the Central Lowlands, lies beneath an extensive lowland occupied by more than 50 lakes.

Geomorphology of Volcanic Terrains. The Traveler rhyolite (Rankin, 1968, 1980; Rankin and Hon, 1987) and an outlier on Soubunge Mountain are geologically and mineralogically comparable (Hon, 1980) with the Kineo rhyolite in the Moose River synclinorium. The topography of the Traveler rhyolite reveals much of its internal structure. Ash-flow tuff beds dip at a moderate angle to the north, and the tops of individual flows form uniform, sloping surfaces inclined to the north, while erosion along more or less perpendicular columnar joints forms steep south-facing slopes (Rankin, 1980). The unmetamorphosed Trout Valley Formation overlies the Traveler rhyolite and crops out to the northwest of the main area of the Traveler exposures. The basal unit of the formation is a matrix supported conglomerate composed almost entirely of clasts of the Traveler rhyolite, probably deposited as a lahar. Overlying the basal unit are medium to fine-grained conglomerates and interbedded sandstone that have been eroded by South Branch Pond Brook and Gifford Brook into steep-walled canyons that resemble many stream valleys in the Cordillera of the western United States.

BOUNDARY MOUNTAINS HIGHLANDS

Topography

This belt of highlands forms the watershed between the St. Lawrence drainage and rivers draining toward the Gulf of Maine. It also is the basis of the international boundary between Maine and the Eastern Townships of Quebec.

The Boundary Mountains Highlands are characterized by an irregular and knobby topography within the Chain Lakes massif and Attean pluton. Linear hills and small ridges are more common in the northern margin of the province, underlain by Silurian and Devonian metasedimentary rocks. Albee and Boudette (1972) observed these distinct topographic expressions in the Attean quadrangle. Although the region is very rugged, variations in relief are not as spectacular as in the Central Maine Highlands. Most of the mountains within the highlands are less than 4000 feet (1220 m) and rise from base elevations no less than 1200 feet (365 m). As in the Central Maine Highlands, mountain peaks also diminish in elevation from west to east. Large lakes and lowlands, other than the Attean basin discussed below, are generally rare and are underlain by plutonic rock or less resistant metasedimentary rocks, such as slate.

Geology

Rocks in the Boundary Mountains Highlands range in age from Precambrian through Early Devonian (Naylor et al., 1973; Boudette and Boone, 1976; Boudette, 1982). The Chain Lakes massif, a relatively resistant quartzo-feldspathic granofels (Albee and Boudette, 1972), underlies the northern part of the anticlinorium. Juxtaposed to the east is the Attean quartz monzonite, which like the Katahdin pluton forms both highlands and lowlands. The core of the anticlinorium plunges north beneath a blanket of Silurian and Lower Devonian metasedimentary and volcanic rocks.

The Late Ordovician Attean quartz monzonite underlies nearly 150 mi^2 (241 km^2) of the Boundary Mountains anticlinorium. A broad lowland (Fig. 16), herein called the Attean basin (1200 ft; 365 m), occupied by the Moose River, No. 5 Bog, and Attean, Little Big Wood, Wood, and Holeb Ponds, overlies 65% of the pluton. Rising up sharply from the lowlands are a number of mountains, such as Catheart Mountain (2363 ft; 720 m), Sally Mountain (2221 ft; 678 m), and Burnt Jacket Mountain (2280 ft; 695 m). These mountains, formed also of the Attean quartz monzonite, contain local dikes of resistant quartz-porpyhry and aplite (Albee and Boudette, 1972). Mineralization and alteration of the pluton, along with faulting and jointing (Fig. 17), have also greatly affected its local weathering characteristics.

LOBSTER MOUNTAIN - MOOSE RIVER LOWLANDS

Topography

Linear ridges and valleys, products of differential weathering and erosion of rocks exposed within the Acadian fold belts, make this region unique. Any vestige of original anticlinal ridges or synclinal valleys has been removed by erosion and the area has been topographically inverted. The broad lowlands area occupied by Moosehead Lake, the largest lake in New England, and the Kennebec River valley are underlain by weak rocks exposed in the core of the Lobster Mountain anticlinorium. Most of the major ridges and mountains, such as Misery Ridge (Misery Knob: 2126 ft; 648 m), Mount Kineo (1806 ft; 550 m), and Big Spencer Mountain (3230 ft; 984 m) are composed of the younger, more resistant rocks down-folded within the Moose River and Roach River synclinoria.

Geology

Three major structural belts (Fig. 3) underlie this lowlands region. They are from west to east: (a) the Moose River synclinorium (MRS), (b) the Lobster Mountain anticlinorium (LMA: Boudette and Boone, 1976; Lobster Lake anticlinorium of Boucot and Heath, 1969), and (c) the Roach River synclinorium (RRS). The topography is probably better correlated with rock type and structure here than in any other region

Figure 16. The Attean basin, viewed here from Catheart Mountain. The basin is underlain by the Attean quartz monzonite and forms the largest lowland area within the Boundary Mountains anticlinorium. Note the moraines which cross the lowlands in the center of the photograph. These rogen moraines are common in basins underlain by plutonic rock (see Caldwell et al., 1985).

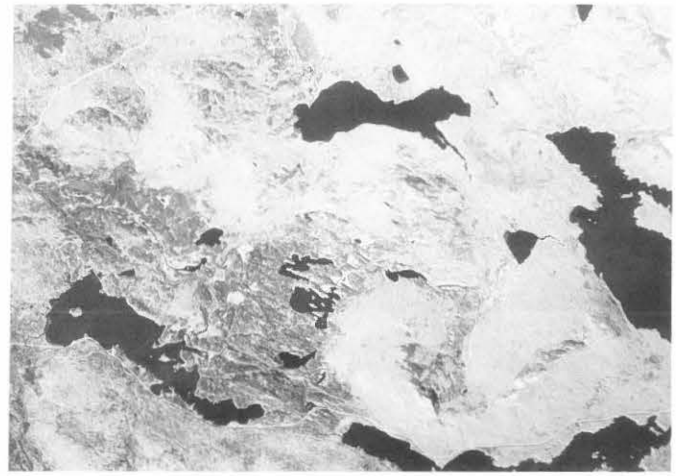


Figure 17. The lowlands to the left (west) are underlain by a highly fractured portion of the Attean pluton. Intense fracturing of the pluton is probably the product of Acadian deformation. (Photo courtesy of Great Northern Paper Company)

of Maine, primarily because it is simply folded and uncomplicated by intrusive events. Unlike the lowlands of the slate belts where large areas are underlain by rocks of similar strength, the Lobster Mountain - Moose River Lowlands are underlain by a variety of lithologies, each having a different topographic expression but occurring along a linear trend. The resulting topography, having a maximum relief of approximately 2200 ft (670 m), consists of long linear or gently arcuate ridges and valleys which reflect the underlying fold structures. The structural belts plunge to the northeast where they and their accompanying topography die out in a belt of Devonian slates near the northern end of Moosehead Lake and Lobster Lake.

Lobster Mountain Anticlinorium. This structural belt is underlain largely by multiply cleaved and relatively weak Cambrian and Ordovician metapelitic rocks (e.g. Hurricane Mountain mélange, Dead River and Kennebec Formations, and portions of the Jim Pond Formation). Weathering of the pelitic Hurricane Mountain mélange (Boone, 1983) and the phyllitic Dead River and Kennebec Formations (Boone, 1973) has formed a broad lowland that extends from Lobster Lake southwestward for about 90 miles (160 km) to Flagstaff Lake (Fig. 18). The Kennebec River follows this lowland and for about 20 miles (32 km), from Moosehead Lake to The Forks, it marks the eastern limb of the Lobster Mountain anticlinorium. At The Forks, the Kennebec leaves its subsequent position and crosses the Central Maine Highlands, even though the broad valley that characterizes the anticlinorium continues southwestward for many miles.

The Hurricane Mountain mélange (Boone, 1983) is composed of exotic blocks surrounded by a scaly, rusty-weathering, pelitic matrix. The mélange underlies the north end of Indian Pond, where it is recognized by a unique topography. The pelite has been deeply eroded to form part of the lake basin, while the

Figure 18. Islands in Indian Pond composed of the mafic and ultramafic exotic blocks in the Hurricane Mountain mélange. The basin portion of the lake is underlain by the mélange matrix which has an easily eroded scaly cleavage. In the far background lies Big Spencer Mountain (center-left), composed largely of the Kineo rhyolite, and Lobster Mountain (far left) and Little Spencer (center right), composed of Ordovician volcanic rocks.

Figure 19. This broad valley of the Kennebec River, occupied here by Indian Pond, is underlain by weak pre-Silurian rocks exposed in the core of the Lobster Mountain anticlinorium. The islands in Indian Pond are exotic blocks of orthoquartzite, serpentinite, and a variety of meta-igneous and metavolcanic rocks in the Hurricane Mountain melange (Boone, 1983).

more resistant "knockers" protrude, forming numerous islands (Fig. 19).

Although the width of the Lobster Mountain anticlinorium is greatest toward the southwest end, the valley that occupies it becomes narrower. Devonian plutons that have intruded this part of the structure have metamorphosed pelitic rocks, producing numerous mountains such as Hurricane and Dead River Mountains which are contained in the Pierce Pond gabbro metamorphic aureole (Lyttle, 1976). The broad valley occupied by the South Branch Dead River, which appears to be an extension of the anticlinorium, is underlain by the Flagstaff Lake Igneous Complex (Boone, 1973). Beyond this point the lowland narrows and continues for several miles into the Rangeley Lakes area and New Hampshire.

Figure 20. View of Mount Kineo looking parallel to strike from the northeast. Mount Kineo and Blue Ridge, in the background to the southwest, are held up by the Kineo rhyolite member of the Tomhegan Formation. Crude columnar jointing controls the steep cliffs on Mount Kineo.

Ordovician volcanics, the most resistant rocks in the Lobster Mountain anticlinorium, form Lobster Mountain (elevation 2359 ft; 719 m) which looms conspicuously over the adjacent lowlands. From Moosehead Lake to Lobster Lake, the Lobster Mountain volcanic rocks dominate the structural belt, forming the highest elevations within this area.

The Moose River and Roach River Synclinoria. According to Boucot and Heath (1969), the Moose River synclinorium contains the thickest sequence of fossiliferous and relatively unmetamorphosed (greenschist facies) Lower Devonian strata in the Appalachians. The Tarratine, Seboomook, and Tomhegan Formations compose the bulk of the rocks within both structures.

The relative resistance of the lithologies composing these formations is clearly demonstrated by topography. Lowlands are underlain by the slates of the Seboomook Formation and relatively weak, rusty-weathering slates and siltstones forming the bulk of the Tomhegan Formation (Boucot, 1961).

Contained also in the Tomhegan Formation is the highly resistant Kineo rhyolite. The Kineo rhyolite member invariably forms steep-sided hills and ridges. Kineo Mountain (Fig. 20) has spectacularly precipitous cliffs on all but the northeast side. A number of other mountains, such as Blue Ridge (1877 ft; 572 m) and Misery Knob (2128 ft; 649 m) to the southwest and Shaw (1657 ft; 505 m), Little Kineo (1927 ft; 587 m), Eagle (1685 ft; 514 m) and Norcross (1615 ft; 492 m) Mountains to the northeast, are composed of the same rhyolite. Topographic inversion is nicely illustrated in the Roach River synclinorium where the Kineo rhyolite is the youngest rock exposed. Originally downfolded into the core of the syncline, the rhyolite now forms Big Spencer Mountain (3230 ft; 984 m), the most prominent mountain in the entire belt.

Adjacent to the Kineo trend, but extending much farther along strike to the southeast, are highlands composed of the

Tarratine Formation (Boucot, 1961). Dark gray sandstone composes 90 percent of the main part of the formation (Boucot and Heath, 1969) and forms a continuous ridge (called Misery Ridge in the northeast portion) which extends for more than 45 miles toward Spencer Lake. A few prominent bumps on Misery Ridge are composed of isolated masses of Kineo rhyolite, some of which are garnetiferous (Boucot and Heath, 1969). Portions of the ridge are also composed, in part, of the very resistant Misery quartzite member of the Tarratine Formation.

At its southwestern terminus, as well as to the north, the Tarratine and overlying Tomhegan Formations are folded into a series of synclines and anticlines. On the south side of the Moose River structure the outcrop belt of the Tarratine Formation broadens substantially and, together with the Kineo rhyolite, supports such mountains as Coburn (3718 ft; 1133 m), Johnson (2600 ft; 792 m), Cold Stream (2120 ft; 646 m) and Williams (2500 ft; 762 m) Mountains. The Tarratine Formation is conspicuously wrapped around the Attean pluton of Ordovician age and forms some of the mountains that overlook the basin underlain by the Attean pluton. During the folding that accompanied the Acadian orogeny, the competent rock of the Attean pluton may have formed a buttress around which the younger rocks were deformed. The Moose River structure pinches out between the Attean pluton and the Chain Lakes massif to the southwest and the Lobster Mountain anticlinorium to the northeast. Further northeast, the Tarratine Formation forms only low hills.

Locally well formed trellis and rectangular drainage systems occur where dominant drainage directions have developed parallel to and across structural strike. Excellent examples of such patterns occur south of Brassua Lake, along the southeast flank of the Moose River synclinorium (Fig. 21c). Streams flowing along strike occupy zones of weak rock. Misery Stream flows within a long, northeast-trending valley excavated in highly cleaved rocks of the Tomhegan Formation. In a parallel valley to the southeast, Churchill Stream occupies a valley formed over the Southeast Boundary fault (Boone, 1970) which separates the the Moose River synclinorium from the Lobster Mountain anticlinorium. The composite Kineo-Tarratine trend forms the linear highlands which divide the two drainage systems. Cutting through the divide are two large wind and water gaps. These gaps, along with numerous northwest- and southeast-trending streams have been excavated along high-angle cross joints. The Canadian Pacific Railroad, Misery Stream (Pond), and Chase Stream are a few features that occupy these gaps. Large esker systems leading into and away from these gaps indicate that they also served as prominent meltwater channels during the last episode of glaciation (Caldwell and Hanson, 1975, 1985).

Moosehead Lake. Moosehead Lake (Fig. 21) is oriented perpendicular to the tectonic strike, parallel to the dominant northwest fractures, and traverses both the Lobster Mountain anticlinorium and Moose River synclinorium. The local width of the lake reflects nicely the relative resistance of the rocks through which it cuts. Pelitic rocks of the Lobster Mountain anticlinorium (Dead River and Hurricane Mountain Formations) and the Devonian Tomhegan and Seboomook Formations underlie the widest portion of the lake. Northeast Bay, a 10-mile-long northeast-trending arm of the lake, fills a valley developed along strike in the Seboomook Formation. Spencer Bay occupies the valley of the Lobster Mountain anticlinorium. The lake narrows where the Tarratine Formation (Kineo Rhyolite Member) and Lobster Mountain volcanics cross.

TECTONIC UPLIFT

Although the development of a regional highlands is largely due to orogenic uplift, the details of the topography, the local basins and highlands for example, are greatly influenced by the rock types which are presently exposed. The study area has been affected by two orogenic events, the Taconic and the Acadian orogenies (Boucot, 1968; Rodgers, 1970), and the present landscape has resulted from a continuous modification of the resultant orogens by erosion. Topographic inversion, the product of differential erosion, has probably occurred several times on a local scale.

Erosion of the mountain belt has exposed rocks with greater structural complexity and higher metamorphic grade toward the southwest. Hon (1980) demonstrated that in the vicinity of the Katahdin pluton, only 3 km (1.8 miles) of erosion have taken place since the Devonian. Based upon studies of the Greenville plutonic belt, deeper erosion depths have been estimated for areas farther southwest (Hon, 1980; Hon and Schulman, 1983). For example, the exposed rocks within the Moxie pluton vary consistently along strike; dunites occur in the southwestern end and are replaced by a northeastwardly progression of norites, troctolites, diorite, and eventually granodiorites at the northeast terminus of the pluton near Jo-Mary Mountain and the Katahdin pluton. Hon conceives of the Moxie pluton as forming a deep, elongate gabbroic intrusion that underwent fractional crystallization, forming a distinctly layered body. Greater uplift and subsequent erosion in the southwest has exposed the deeper ultramafic rocks. Thus, as one moves southwestward along strike, progressively deeper levels are encountered.

Hon (1980) describes Acadian plutons toward the southwestern end of the Central Maine Highlands, such as the Lexington pluton, that were emplaced under much higher pressures than were plutons such as the Katahdin. Also, the southern terminus of the Moxie pluton was formed 4 mi (6.5 km) deeper than was the northern end where it is in contact with the Katahdin pluton, 45 mi (75 km) to the northeast. From this evidence and by noting the regional change in metamorphic isograds (see Doyle, 1967, and Osberg et al., 1985), Hon and Schulman (1983) determine a 5-degree upward regional tilt of the Acadian orogen toward the southwest. This suggests that at some time the southwestern portion of the Central Maine Highlands was significantly higher following the Acadian orogeny than was the northeastern end.

Dewey and Kidd (1974) assumed that differences in the intensity of tectonic activity along the Appalachians accounted

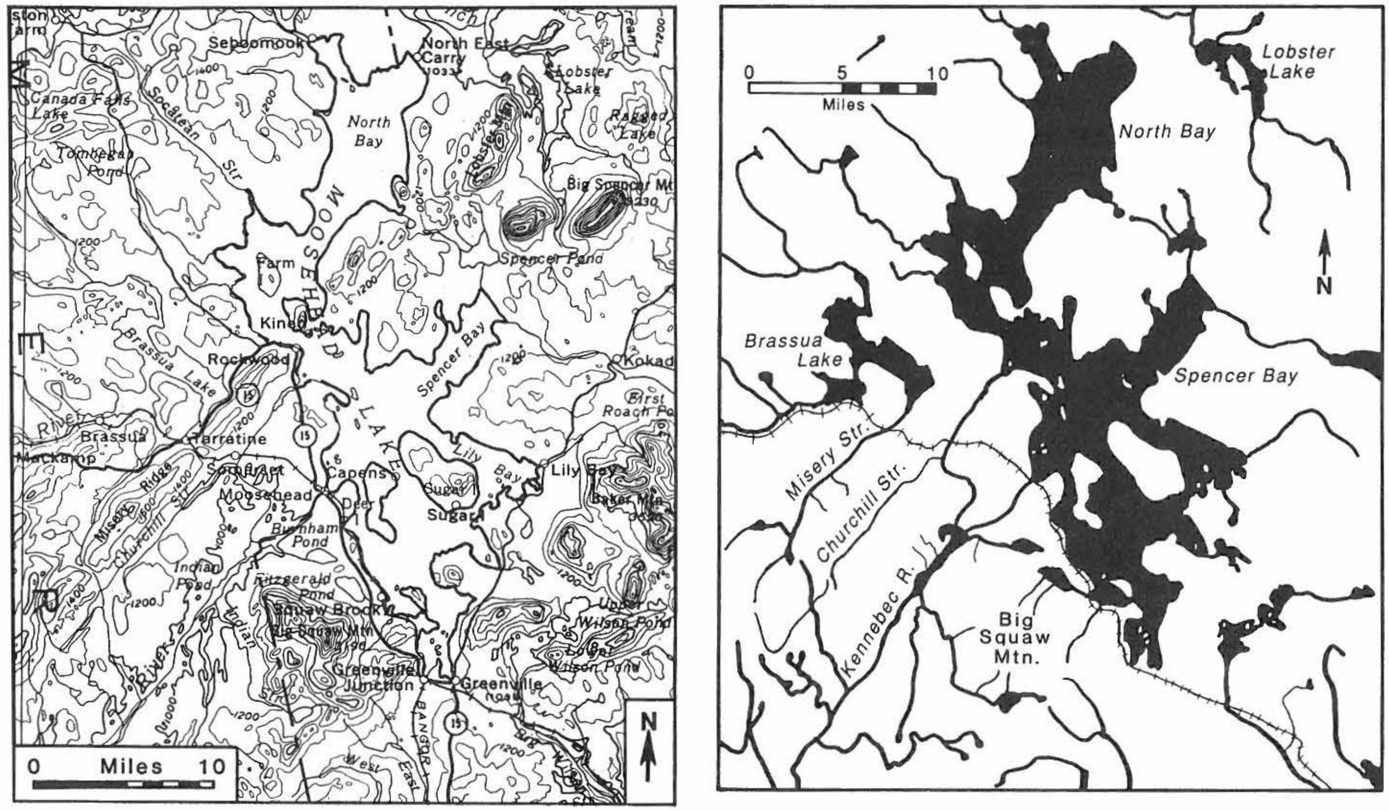


Figure 21a. The southeasterly trending axis of the lake cuts across regional strike and parallels the trend of many high-angle joints and faults. The two large northeast-trending bays, North and Spencer Bay, occupy regions along strike where weak rocks have been excavated. The northwestern portion of the region lies within the Lobster Mountain - Moose River Lowlands and is characterized by ridges and valleys formed by the differential erosion of rocks within open, asymmetrical folds. The region to the southeast of the Kennebec River lies in the Maine Central Highlands and has a more irregular topography produced by the intrusion of plutons and the development of hornfels mountains.

Figure 21b. The drainage system developed over the Lobster Mountain - Moose River Lowlands has preferentially developed along two trends; northeast and southeast. Where streams are equally well developed along both trends, the drainage systems are rectangular; and in regions where one trend is dominant, such as along Misery and Churchill Streams, a trellis pattern is evident. In the south-central portion a radial pattern has developed around the summit of Big Squaw Mountain. Radial drainage patterns are characteristic of most of the mountainous regions of the Central Maine Highlands.

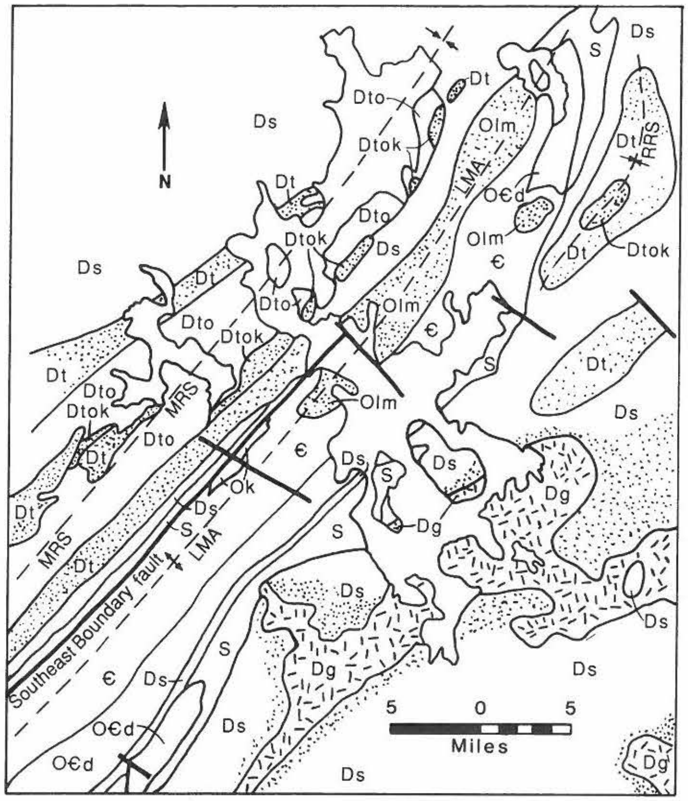
Figure 21. Moosehead Lake and surrounding topography.

for variations in uplift and erosion, and ultimately in the topography of mountain ranges. The tectonic map of the Appalachians compiled by Williams (1978) shows that most of Maine lay within a reentrant during the Acadian collision, while New Hampshire and southern New England were in a promontory that bore the brunt of the collision. In Maine the collision would have decreased in intensity from west to east. The greater intensity of the deformation experienced in the west would have produced higher mountainous terrain.

Possibly two other periods of uplift affected western portions of the Central Maine Highlands. The emplacement of the Sebago pluton in the Carboniferous period may have heated the overlying rocks to cause significant uplift (Guidotti et al., 1986; Lux and Guidotti, 1985). Guidotti et al. (1986) indicate that as much as 10 km of erosion has occurred in order to expose the Sebago pluton. Mesozoic intrusion in the White Mountains of New Hampshire may have also played a role in causing heating of the country rocks and further uplift in that area (Crough, 1981). As the Central Maine Highlands were eroded, isostatic uplift brought deeper, higher-grade metamorphic rocks to the surface in the southwest compared with the rocks to the northeast.

DRAINAGE SYSTEM

All of the large river systems in Maine (e.g. Kennebec, Piscataquis, Penobscot, and Androscoggin) head in the mountainous regions of north-central Maine or in the White Mountains of New Hampshire. Several of the rivers flow for long distances eastward, before turning southward toward the sea. There are a number of lakes within the headwaters of these rivers, but there are none of natural origin downstream of where the rivers make their turn to the south (Denny, 1980). Possible explanations of the preponderance of lakes in the upper reaches of these rivers includes locally low gradients encountered by headwater streams



Dg -Gabbro
Ds -Seboomook Group
(exclusive of the Tomhegan and Tarratine Fms.)
Includes: Seboomook Fm., Hildredth Fm.
Dt -Tarratine Fm.
Dto -Tomhegan Fm.
Dtok -Kineo Rhyolite Member
S -Undifferentiated Silurian rocks
Olm -Lobster Mountain Volcanics
Ok -Kennebec Fm.
O€d -Dead River Fm.
€ -Undifferentiated Cambrian
Includes: Hurricane Mt. Fm., Jim Pond Fm.

Figure 21c. Generalized map of the bedrock geology and geomorphology of the Moosehead Lake area (modified from Boone, 1983). The more resistant rocks are stippled. Faults are indicated by thick black lines. The Southeast Boundary fault locally separates the Lobster Mountain anticlinorium (LMA) and Moose River synclinorium (MRS). The Roach River syncline (RRS) lies in the northeast corner of the map. North Bay occupies a broad region underlain by the weak slates of the Tomhegan Formation and Spencer Bay lies in an area of excavated Cambrian rock. The southeastern end of the lake, which is also quite broad, is underlain by the Moxie pluton. Note that the rocks of the Seboomook Group, in this case the Carrabassett Formation, are indicated as being both weak and resistant. Adjacent to the pluton, these rocks have been contact metamorphosed and form the highest peaks in the map area. In the far southeastern corner lies a portion of the Onawa pluton; the surrounding stippled regions are Boarstone and Barren Mountains.

developed in weak slates and plutonic rocks, and obstructions to flow presented by structures oriented perpendicular to regional slope. There may also be a possibility that lake basins above the limit of late-glacial marine submergence (Thompson and Borns, 1985) were occupied by ice blocks which prevented depressions from being filled with glacial meltwater sediments (Caldwell et al., this volume). In the Lobster Mountain - Moose River Lowlands and Central Maine Highlands, resistance varies tremendously across strike. Rivers may flow for several miles parallel to resistant highlands until a more southerly channel is encountered. Channels heading south across strike are commonly both consequent and structurally controlled, having been preferentially excavated in cross-joints and faults which parallel the regional slope (see Fig. 21).

South of the Central Maine Highlands, rivers can more easily maintain their southerly channels and have carved through the weak slate underlying much of the Central Maine Lowlands. Exceptions occur where more resistant belts of the Madrid Formation are exposed (e.g. Charleston Ridge). Drainage in the Coastal Province is characterized by numerous lakes which have developed in plutonic rocks of the Avalon Terrane.

Local radial drainage networks are commonly well developed around mountains of the Central Maine Highlands. In the Central Maine Lowlands, patterns are more dendritic, being less affected by regional structure as they cut across weak slates. Rectangular and trellis drainage patterns are locally well developed in the Lobster Mountain - Moose River Lowlands where fold belts, containing alternate zones of weak and resistant rock, and fracture zones lie at mutually perpendicular angles.

SUMMARY

Our work in the mountainous area of north-central Maine leads us to conclude that a thorough knowledge of the local bedrock is required in order to understand the geomorphology of an area. We have presented a number of specific examples that illustrate the control of lithology and structure on topography. As a general rule, each major fold belt in Maine locally demonstrates a unique relationship between bedrock geology and topography. However, the morphology of a fold belt may vary regionally along strike in response to lithologic changes produced by variations in the intensity of metamorphism and deformation.

In north-central Maine, the greatest topographic relief occurs in regions of intermediate to mafic Acadian plutonism. Highlands are supported either by hornfelsic rock in contact metamorphic aureoles, or by volcanic or granophyric rock. Lowlands are typically underlain by plutons, or cleaved and fractured, low-grade regionally metamorphosed metasedimentary rocks. Local landforms in which no direct relationship between topography and geology exists probably attest to a recently unroofed lithology that has not yet been shaped by erosion.

ACKNOWLEDGMENTS

Our knowledge of the mountainous regions of north-central Maine was gained mostly through field work supported by the Maine Geological Survey, Walter Anderson, State Geologist. We have also profited greatly from discussion with Gary Boone and Rudi Hon. Dan Cochran, Great Northern Paper Company, Millinocket Maine, assisted us in numerous ways, including the loan of aerial photographs and permission to enter otherwise restricted areas. Steve Kite of the University of West Virginia, Woodrow Thompson of the Maine Geological Survey, and an anonymous reviewer made valuable suggestions that improved the manuscript. Finally, our respective institutions granted us sabbatical leave during the Fall of 1986, which allowed us to be in the field area for an extended period when trees were leafless.

REFERENCES CITED

Albee, A. L., 1961, Boundary Mountain anticlinorium, west-central Maine and northern New Hampshire: U.S. Geol. Surv., Prof. Paper 424-C, p. C51-C54.

Albee, A. L., and Boudette, E. L., 1972, Geology of the Attean quadrangle, Somerset County, Maine: U.S. Geol. Surv., Bull. 1297, 110 p.

Boone, G. M., 1970, Tectonic and metamorphic history of Lower Devonian rocks in the Carrabassett Valley north of Kingfield, Maine, *in* Boone, G. M. (ed.), New England Intercollegiate Geological Conference guidebook for field trips in the Rangeley Lakes -- Dead River basin region, western Maine, p. A-2, 1-18.

Boone, G. M., 1973, Metamorphic stratigraphy, petrology, and structural geology of the Little Bigelow Mountain map area, western Maine: Maine Geol. Surv., Bull. 24, 136 p.

Boone, G. M., 1983, The Hurricane Mountain Formation mélange and unconformably overlying Lower to Middle Ordovician volcanics, Brassua Lake and Moosehead Lake quadrangles, *in* Caldwell, D. W., and Hanson, L. S. (eds.), New England Intercollegiate Geological Conference guidebook for field trips in the Greenville-Millinocket regions, north-central Maine, p. 31-44.

Boudette, E. L., 1982, Ophiolite assemblage of early Paleozoic age in central western Maine, *in* St-Julien, P., and Beland, J. (eds.), Major structural zones and faults of the northern Appalachians: Geol. Assoc. Canada, Spec. Paper 24, p. 209-230.

Boudette, E. L., and Boone, G. M., 1976, Pre-Silurian stratigraphic succession in central Maine, *in* Page, L. R. (ed.), Contributions to the stratigraphy of New England: Geol. Soc. Amer., Mem. 148, p. 76-96.

Boucot, A. J., 1961, Stratigraphy of the Moose River synclinorium: U.S. Geol. Surv., Bull. 1111-E, p. 153-188.

Boucot, A. J., 1968, Silurian-Devonian of northern Appalachians, *in* Zen, E-an, Hadley, J. B., and Thompson, J. B., Jr. (eds.), Studies of Appalachian geology--northern and maritime: Interscience, New York, p. 83-94.

Boucot, A. J., and Heath, E. W., 1969, Geology of the Moose River and Roach River synclinoria, northwestern Maine: Maine Geol. Surv., Bull. 21, 117 p.

Caldwell, D. W., and Hanson, L. S., 1975, Reconnaisance surficial geologic map of the Brassua Lake quadrangle, Maine: Maine Geol. Surv., Open-File Map 76-5.

Caldwell, D. W., and Hanson, L. S., 1985, The geomorphology of Acadian fold belts, Greenville-Rockwood area, north-central Maine: Geol. Soc. Amer. Abs. with Prog., v. 17, p. 9.

Caldwell, D. W., and Hanson, L. S., 1987, Geomorphology and glacial geology of the Mt. Katahdin region, north-central Maine, *in* Roy, D. C. (ed.), Centennial field guide, Volume 5: Geol. Soc. Amer., Northeastern Section, p. 303-306.

Caldwell, D. W., Hanson, L. S., and Thompson W. B, 1985, Styles of deglaciation in central Maine, *in* Borns, H. W., Jr., LaSalle, P., and Thompson, W. B. (eds.), Late Pleistocene history of northeastern New England and adjacent Quebec: Geol. Soc. Amer., Spec. Paper 197, p. 45-58.

Crough, S. T., 1981, Mesozoic hotspot epeirogeny in eastern North America: Geology, v. 9, p. 2-6.

Davis, W. M., 1909, Geographical essays: Ginn and Co., New York, p. 249-278.

Denny, C. S., 1980, Geomorphology of New England: U.S. Geol. Surv., Prof. Paper 1208, 18 p.

Dewey, J. F., and Kidd, W. S. F., 1974, Continental collision in the Appalachain-Caledonian orogenic belt: variations related to complete and incomplete suturing: Geology, v. 2. p. 543-546.

Doyle, R. G., 1967, Preliminary geologic map of Maine, Maine Geol. Surv., scale 1:500,000.

Espenshade, G. H., 1972, The geology of the Moxie pluton, Moosehead Lake--Jo-Mary Mountain area, Piscataquis County, Maine: U.S. Geol. Surv., Bull. 1340, 40 p.

Espenshade, G. H., and Boudette, E. L., 1967, Geology and petrology of the Greenville quadrangle, Maine: U.S. Geol. Surv., Bull. 1241-f, 60 p.

Goldich, S. S., 1938, A study of rock weathering: Jour. Geol., v. 46, p. 17-58.

Goldthwait, J. W., 1914, Remnants of an old graded upland on the Presidential Range, New Hampshire: Am. Jour. Sci., 4th series, v. 37, p. 451-463.

Griscom, A., 1976, Bedrock geology of the Harrington Lake area, Maine: Ph.D. dissert., Harvard Univ., Cambridge, Massachusetts, 373 p.

Guidotti, C. V., Gibson, D., Lux, D. R., DeYoreo, J., and Cheney, J. T., 1986, Carboniferous metamorphism on the north (upper) side of the Sebago batholith, *in* Newberg, D. W. (ed.), New England Intercollegiate Geological Conference guidebook for field trips in southwestern Maine, p. 306-341.

Hack, J. T., 1979, Rock control and tectonism - their importance in shaping the Appalachian Highlands: U.S. Geol. Surv., Prof. Paper 1126-B, p. B1-B17.

Hanson, L. S., 1988, Stratigraphy of the Jo-Mary Mountain area with emphasis on the sedimentary facies and tectonic interpretation of the Carrabassett Formation: Ph.D. dissert., Boston Univ., Boston, Massachusetts, 314 p.

Hanson, L. S., and Caldwell, D. W., 1983, Glacial deposits and shoreline features in Maine lakes: Geol. Soc. Amer., Abs. with Prog., v. 15, p. 193.

Hon, R., 1980, Geology and petrology of igneous bodies within the Katahdin pluton, *in* Roy, D. C., and Naylor, R. S. (eds.), New England Intercollegiate Geological Conference guidebook for field trips in northeastern Maine and neighboring New Brunswick, p. 65-79.

Hon, R., and Schulman, J., 1983, The petrology of the central part of the Moxie pluton, *in* Caldwell, D. W., and Hanson, L. S. (eds.), New England Intercollegiate Geological Conference guidebook for field trips in the Greenville-Millinocket regions, north-central Maine, p. 103-116.

Lux, D. R., and Guidotti, C. V., 1985, Evidence for extensive Hercynian metamorphism in western Maine: Geology, v. 13, p. 696-700.

Lyons, J. B., Boudette, E. L., and Aleinikoff, J. N., 1982, The Avalonian and Gardner zones of central eastern New England, *in* St. Julien, P., and Beland, J. (eds.), Major structural zones and faults in the northern Appalachians: Geol. Assoc. Canada, Spec. Paper 24, p. 43-66.

Lyttle, P. T., 1976, Petrology and structure of the Pierce Pond gabbroic intrusion and its metamorphic aureole, western Maine: Ph.D. dissert., Harvard Univ., Cambridge, Massachusetts, 188 p.

Naylor, R. S., Boone, G. M., Boudette, E. L., Ashenden, D. D., and Robinson, P., 1973, Pre-Ordovician rocks in the Bronson Hill and Boundary Mountain anticlinoria, New England (abstract): Am. Geophys. Union, Transactions, v. 54, p. 495.

Osberg, P. H., Hussey, A. M., II, and Boone, G. M., 1985, Bedrock geologic map of Maine: Maine Geol. Surv., scale 1:500,000.

Philbrick, S. S., 1936, The contact metamorphism of the Onawa pluton, Piscataquis County, Maine: Am. Jour. Sci., 5th ser., v. 31, no. 181, p. 1-40.

Rankin, D. W., 1968, Volcanism related to tectonism in the Piscataquis volcanic belt, an island arc of Early Devonian age in north-central Maine, *in* Zen, E-an, White, W. S., Hadley, J. B., and Thompson, J. B., Jr. (eds.), Studies in Appalachian geology--northern and maritime: Interscience, New York, p. 355-369.

Rankin, D. W., 1980, The Traveler rhyolite and its Devonian setting, Traveler Mountain area, Maine, *in* Roy, D. C., and Naylor, R. S. (eds.), New England Intercollegiate Geological Conference guidebook for field trips in northeastern Maine and neighboring New Brunswick, p. 98-113.

Rankin, D. W., and Hon, R., 1987, Traveler rhyolite and overlying Trout Valley Formation and the Katahdin pluton; a record of basin sedimentation and Acadian magmatism, north-central Maine, *in* Roy, D. C. (ed.), Centennial field guide, Volume 5: Geol. Soc. Amer., Northeastern Section, p. 293-301.

Reks, I. J., and Gray, D. R., 1982, Pencil structure and strain in weakly deformed mudstone and siltstone: Jour. Struc. Geol., v. 4, no. 2, p. 161-176.

Richter, D. A., and Roy, D. C., 1976, Prehnite-pumpellyite facies metamorphism in central Aroostook County, Maine, *in* Lyons, P. C., and Brownlow, A. H. (eds.), Studies in New England geology: Geol. Soc. Amer., Mem. 146, p. 239-263.

Rodgers, J., 1970, Tectonics of the Appalachians: Interscience, New York, 217 p.

Thompson, P. J., 1985, Stratigraphy, structure, and metamorphism in the Monadnock quadrangle, New Hampshire: Contribution No. 58, Univ. Massachusetts, Amherst, Massachusetts, 191 p.

Thompson, W. B., and Borns, H. W., Jr., 1985, Surficial geologic map of Maine: Maine Geol. Surv., scale 1:500,000.

Thompson, W. F., 1960, The shape of New England mountains: Appalachia, part I, Dec. 1960, p. 145-159.

Toppan, F. W., 1932, The geology of Maine: M.S. thesis, Union College, Schenectady, N.Y., 141 p.

Toppan, F. W., 1935, The physiography of Maine: Jour. Geol., v. 43, p. 76-87.

Vehrs, T. I., 1975, Tectonic, petrologic and stratigraphic analysis of the Bigelow Range, Stratton and Little Bigelow Mtn. quadrangles, northwestern Maine: Ph.D. dissert., Syracuse University, Syracuse, N.Y., 196 p.

Williams, H., 1978, Tectonic-lithofacies map of the Appalachian orogen: Memorial University of Newfoundland, Map no. 1.